Application of Pneumatic Soft Mechanism to a Human Friendly Robot

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ABSTRACT

When robots work together with a human or contact with a human body directly in such as a medical welfare field, in order to avoid an accident from crash and so on, a flexibility is required for the robot.

The purpose of this study is to realize a safe mechanism for a human-friendly robot. The soft mechanism comprises a soft actuator and a soft sensor. The soft actuator and soft sensor are made of a silicone rubber body and driven with a pneumatic power.

In this paper, the structure and the fundamental characteristics of soft actuator and soft sensor are described, and then the structure and the fundamental operation of the developed soft hand are shown.

KEY WORDS

Soft robot hand, Soft mechanism, Pneumatics, Soft actuator, Soft tactile sensor

INTRODUCTION

For the coming advanced age society, there may not be enough working people in various fields. Especially, in the high physical burden field such as medical welfare, agriculture and so on, the lack of working people may become a serious problem. In order to deal with such a situation, it is effective to introduce a human friendly robot.

When robots work together with a human or contact with a human body directly in such as a medical welfare field, in order to avoid an accident from crash and so on, a flexibility is required for the robot^[1].

In this study, to realize a robot which can work together with human or handle fragile objects, a soft robot hand constructed with a soft mechanism^{[2][3]} has been developed. The developed robot hand made of silicone rubber body and driven with a pneumatic power.

A pneumatic soft mechanism provided with the flexibility owing to silicone rubber can easily achieve bending and torsion motions without joint, bearing and so on. Depending on the flexibility of the hand, this hand can accomplish almost the same motion as a human hand. Therefore, this hand can contact with a fragile object without complicated control method.

In this paper, the structures and the fundamental characteristics of soft mechanisms are described, and then the structure and the fundamental operation of the soft hand are shown.

PNEUMATIC SOFT MECHANISM

ROTARY-TYPE SOFT ACTUATOR

Fig.1 shows a structure of the developed actuator. This actuator consists of a silicone rubber ball with an outer diameter of 12[mm], an inner diam-

eter of 10[mm] and a silicone rubber bar with an outer diameter of 10[mm]. The silicone rubber ball is made by forming a liquid silicone rubber with a metal mold. A rotary-type soft actuator of which the ball and the bar are covered with a fiber tube. This fiber tube is made from polyester fiber tube as shown in Fig.1(b). The bended side of actuator is reinforced with fiber to inhibit expanding in the axial direction. Therefore, when the compressed air is supplied into the actuator, it bends in only the circumferential direction without expanding in the axial direction as shown in Fig.2.

Fig.1: Structure of rotary-type soft actuator

Fig.2: Operation of rotary-type soft actuator

Fig.3 shows the relation between the inner pressure and the bending angle. The change of the angle becomes small over 300[kPa], because the extension of the silicone rubber gradually nears the elastic limit. Enough large bending angle can be obtained.

AIR MUSCLE

To realize components for more complicated motion such as the root of thumb, the small size air muscle is developed. Since deformation of mechanism (bending, torsion) can be realized by the small

Fig.3: Relation between P and $\delta\theta$

sized air muscle easily, many kinds of complicated motions become possible.

In the following, the structure and the fundamental property of this actuator is described.

Fig.4 shows the structure of the air muscle. It consists of silicone rubber tube (outer diameter 4[mm], inner diameter 3[mm]). The tube is reinforced with polyester fibers.

Fig.4: Structure of air muscle

Fig.5(a) shows the initial state of the developed air muscle. When the compressed air is supplied to the air muscle, it contracts in the axial direction as shown in Fig.5(b).

Three kinds of air muscles ($l_0 = 40, 70, 95\text{mm}$) have been experimentally examined. l_0 is the initial length of the air muscle. The displacement when the compressed air is supplied to the air muscle from 0[kPa] to 500[kPa] at 50[kPa] interval is measured. Fig.6 shows the relations between the inner pressure and the displacement. The experimental results show that the displacement saturates with an increase in the inner pressure. The elastic limit of silicone rubber causes this saturation.

The relation between the inner pressure and the contraction force of the air muscle is measured. The actuator is fixed at the initial length in the measurement. The experimental result shown in Fig.7, it proves that the contraction force increases with an

(a) Initial state

(b) Pressurized state

Fig.5: Operation of air muscle

Fig.6: Relation between P and Δl

increase in the length of the air muscle.

Fig.7: Relation between P and F

The relations between the contraction ratio and the contraction force of each air muscle are shown in Fig.8. In the measurement, the fixed distance of the air muscle is decreased at $\Delta l/l_0 = 0.5$ intervals at the constant inner pressure of 500[kPa]. It is shown that the contraction force decreases almost linearly along with an increase in the contraction ratio.

Fig.8: Relation between $\frac{\Delta l}{l_0}$ and F

TACTILE SOFT SENSOR

Sensors used in the soft hand should be provided with the flexibility to keep the softness of the mechanism. For this purpose, the pressure measurement type tactile soft sensor is developed. Fig.9 shows the developed tactile sensor.

(a) Structure

(b) Outlook

Fig.9: Tactile soft sensor

This sensor consists of cylindrical silicone rubber with an outer diameter 16[mm], inner diameter 15[mm]. The cylindrical silicone rubber is made by forming a liquid silicone rubber with a metal mold.

Fig.10(a) shows the initial state of the sensor. When the external force is applied to it, the inner pressure of the sensor increases according to the deformation of cylindrical silicone rubber as shown in Fig.10(b). A tactile information can be detected by measuring the inner pressure change with a pressure sensor.

Fig.11 shows the relation between the applied external force and the inner pressure of the sensor. It is difficult for this sensor to detect the applied force smaller than 1.0[N], where the inner pressure is very small. Almost linear relation is obtained over 1.0[N].

Fig.10: Principle of tactile soft sensor

Fig.11: Relation between F and P

SOFT HAND

FUNDAMENTAL OPERATION

Fig.12 shows the structure and the outlook of the soft hand. This soft hand consists of the soft finger and the air muscle. The mass of hand is 900[g]. The length is 185[mm]. It has the same size as human. The soft finger has three joints as shown in Fig.13. The rotary-type soft actuators are put in position at intervals of 25[mm]. The disposition of the air muscle is decided by referring the human muscle. This hand can operate almost same as a human hand as shown in Fig.14.

The scene when the hand grasps three kinds of objects is shown in Fig.15. The grasping objects are a soft ball with an outer diameter of 90[mm], a mass of 170[g], a cubical wood with a length of 50[mm], a mass of 75[g] and a balloon with an outer diameter of 95[mm], a mass of 2[g]. The common and constant inner pressures are applied to the actuator and the air muscle. The inner pressures are 400 and 150 [kPa], respectively. This hand can grasp objects with various characteristics such as a shape and a weight, depending on the flexibility of the mechanism.

Fig.12: Soft hand

Fig.13: Outlook of soft finger

CONTACT MOTION

By installing tactile soft sensor at the top of the finger, the soft hand can detect contact force. In the following, the contact motion with a constant force is discussed.

This hand contacts with a soft ball and a balloon at the constant force as shown in Fig.16.

Fig.14: Fundamental operation of soft hand

Softball

Cubical wood

Balloon

Fig.15: Scene of grasping motion

Softball

Balloon

Fig.16: Scene of contact motion

In the experiment, the inner pressure of the rotary actuator is defined by the force control system as shown in Fig.17. The inner pressure of the air muscle is constant value. F_r , P_r represent the desired contact force and the reference inner pressure of the rotary actuator, respectively. F , P represent the measured values of the rotary actuator. F , P are detected by the tactile soft sensor and the pressure sensor. C represents PI controller. In the case of the softball and the balloon, the inner pressures of the air muscle are 150 and 50[kPa], respectively.

Fig.18 shows the experimental results of contact

motion. The desired contact force F_r is 1.0, 1.5, 2.0[N]. In the case of the softball, the little finger can not contact with the object, then the little finger is not used in this experiment. As shown in the figures, this hand can contact with a objects with various characteristics, depending on detecting contact force. Especially, where this hand can contact with a softness object such as a balloon, this hand is effective to contact with a fragile object.

(a) Softball

(b) Balloon

Fig.18: Contact motion with object

Fig.19 shows the experimental results of contact motion when a vibration is applied to the softball in the x axis direction. In the experiment, the vi-

Fig.17: Force control system

bration with an amplitude of 2.5[mm] , a frequency of 5[Hz] starts at 10[s]. When the vibration is applied to the object, the contact forces agree with the desired contact force. From the results mentioned above , when the external force is applied to this hand , this hand can grasp objects certainly too.

Fig.19: Contact motion with softball

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CONCLUSION

In the paper , the structures and the fundamental characteristics of soft mechanisms have been described , and then the structure and the fundamental operation of the soft hand have been described.

By applying the flexibility to the hand , the hand can operate almost same as a human hand.

When a robot contacts with a fragile object such as a human body or fruits , a robot is required a delicate motion. In this case , the soft hand is effective because this hand with a flexibility can contact with a fragile object without complicated control method.

The next subject of the study is to apply to grasping the delicate object such as a human body or fruits and so on.